DIURNAL AND SEASONAL TRENDS IN CARBON DIOXIDE CONCENTRATIONS IN CORN AND SOYBEAN CANOPIES AS AFFECTED BY TILLAGE AND IRRIGATION*

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ABSTRACT

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Most crops have higher photosynthetic rates when canopy CO_2 concentrations are maintained at high levels. There is little information available on managing the soil and plants to maximize the CO_2 concentration within the plant canopies. The objective of this work was to characterize the effect of tillage and irrigation on CO_2 concentrations in corn and soybean canopies at 10 cm above the soil surface and midway in the plant canopy. Emphasis was placed on continuous measurements to evaluate the dynamic effects of the microclimate, both in the short term and seasonal trends. CO_2 concentrations were measured sequentially every 30 min using an infrared gas analyzer with a switching solenoid system and a calculator-controlled data acquisition system. Soil temperatures and microclimate data were also measured hourly. Small differences in CO_2 concentrations between corn and soybeans were noted. Effects of irrigation, residue and tillage were minor. Occasional large diurnal fluctuations with maximum CO_2 concentrations at night were associated with low winds and warm temperatures. Extreme daily minimum and maximum CO_2 concentrations ranged from 285 to 800 μmol mol^{-1} for the 2 years of this study. However, typical minimum and maximum values ranged from 320 to 450 μmol mol^{-1}. The seasonal trends in CO_2 concentrations showed that both maximum and minimum occurred around flowering, which corresponded to maximum canopy development. The results suggested adequate mixing within both the corn and the soybean canopies, and that soil respiration modified by tillage and irrigation would be inefficient for CO_2 fertilization due to rapid loss of CO_2 from the canopy.

INTRODUCTION

There are limited data on the natural patterns of CO_2 concentrations in agricultural systems, where the strongest sinks for CO_2 exist. Some CO_2 con-

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centrations over time and spatial gradient measurements have been made close to a sugar beet canopy (Brown and Rosenberg, 1970), corn canopy (Allen, 1971) and wheat canopy (Pearman and Garratt, 1973). These results are limited to individual crops and small fields, and show a dramatic diurnal course of CO_2 concentrations that are considerably greater immediately above the crop canopy than at some higher elevation. CO_2 concentrations at night ranged widely and reached 450–500 μmol mol^{-1} at levels close to the canopy, especially on calm nights. Wind speed and nocturnal CO_2 concentrations have been shown to be inversely related (Brown and Rosenberg, 1970, 1971; Allen, 1971; Verma and Rosenberg, 1976). This daily fluctuation in CO_2 concentration is superimposed on an annual course of CO_2 concentration that appears to be related to the seasonal climatic changes and crop growth. Verma and Rosenberg (1975) showed that the annual fluctuations resulted in a minimum CO_2 concentration that ranged from 295 to 300 μmol mol^{-1} during late July and August, with a maximum of $\sim$328–332 μmol mol^{-1} during the winter months of 1972–73. The minimum CO_2 concentrations during the summer months are related to vigorous photosynthetic activity. Verma and Rosenberg (1976) have shown that the accumulation or dispersion of respired CO_2 depends on the atmospheric thermal stratification.

The release of CO_2 from the soil to the atmosphere is an important part of the carbon cycle. Some of the CO_2 used by the plants in photosynthesis comes directly from that released in the soil and from root respiration into the plant canopy. Moss et al. (1961) has shown that this part of the CO_2 from the soil can vary from as much as 5 to 100% of the total amount assimilated by the plants, depending on the radiation intensity. Reports by Monteith et al. (1962, 1964) and Denmead (1969) indicated that the flux of CO_2 from the soil beneath the crop accounts for $\sim$10–15% of that used in photosynthesis. Monteith et al. (1964) calculated that the amount of soil carbon assimilated by the crop was $\sim$6% of the net carbon uptake for rapidly growing grass in the spring and as much as 20% for other crops during the summer months. The rate of CO_2 evolution from the soil in the field has been shown to depend very strongly on biological and environmental factors, primarily root respiration, soil, temperature and soil water content (Wildung et al., 1975; Gupta and Singh, 1981; Orchard and Cook, 1983; Da Costa et al., 1986b; Buyanovsky et al., 1983, 1986).

These results suggest that even under field conditions any additional supply of CO_2 should provide a substantial increase in the crop production. However, field applications of CO_2 fertilization have met with limited success (Harper et al., 1973a, b; Allen, 1979). Allen et al. (1974) showed that the CO_2 concentration decreased rapidly with height within a corn canopy in spite of high CO_2 fertilization rates at ground level. Their simulations indicate that CO_2 enrichment under natural field conditions would be very inefficient because of the rapid loss of added CO_2 to the atmosphere and the relatively small build-up of CO_2 near the leaves at the top of the canopy, where light is available for photo-

synthesis. Allen (1979) showed that only a 10% efficiency could be expected under conditions of low wind and a high release rate, while Harper et al. (1973a) showed 8–33% efficiency depending on solar radiation. Using some simple assumptions, Takami and van Bavel (1975) showed that the CO_2 release rates must be quite large before substantial increases in crop yield would occur.

Many of the previously mentioned field investigations evaluating the dynamics of CO_2 concentration were measured above the crop canopy. There is limited information available on the CO_2 fluctuations in the canopy or near the soil surface (Knipling et al., 1970; Allen, 1971; Desjardins et al., 1978). The effect of various soil management practices on the CO_2 concentrations near the soil surface in developing corn and soybean canopies has received limited attention. The specific objective was to evaluate the effect of tillage and irrigation on the CO_2 concentrations in developing corn and soybean canopies 10 cm above the soil surface and at mid-canopy. Emphasis was placed on continuous measurements in the field to evaluate the dynamic effects of the microclimate, both on a short-term and seasonal basis.

MATERIALS AND METHODS

This research was conducted during 1985 and 1986 as part of a larger study evaluating the effect of conservation tillage and irrigation on water use efficiency. This experiment was conducted on a Sioux sandy loam (family sandy skeletal mixed, subgroup Udorthentic Haploboroll) at the West Central Experiment Station in Morris, Minnesota (latitude 45°35′ N, longitude 95°55′W, elevation 344 m). Climate in this area is sub-humid with most of the rainfall occurring during the summer growing months. The soil profile is 0.46 m of sandy loam overlaying a very coarse gravel with an available water holding capacity of <60 mm in the rooting depth. Droughty conditions usually exist because of shallow root development, low water holding capacity and erratic rainfall. The organic matter content varies from 5 to 7% in the 0–15-cm depth.

Conventional tillage consisted of fall plowing, spring harrowing and conventional planting. Both no-till and conventional-till plots were planted using a no-till planter. Fertilizer (291, 29 and 29 kg ha^{-1} as N, P and K, respectively) was incorporated as part of the planting operation. Both corn (Pioneer 3906*) and soybean (Evans-Maturity Group 0) were planted in conventional 0.76-m row spacing at 88 920 and 642 200 plants ha^{-1}. The crops were sprinkler irrigated with ~50 mm per irrigation when the soil matric potential at the 0.3-m depth was −30 kPa. The non-irrigated treatments received only natural rainfall. All treatments were replicated four times.

Canopy height was measured from the soil surface using standard tech-

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niques. Leaf area index (*LAI*) and biomass were measured periodically by destructive sampling of four corn plants and 0.5 m of soybean row from each of the four replicates. Leaves were removed and their area measured with a LI-COR LI-3000 leaf area meter. The biomass samples were dried at 80°C and converted to g m^{-2} using the plant population at the end of the season.

Both corn and soybean were planted on 20 May (DY 140) 1985 and 15 May (DY 135) 1986. The growing seasons were characterized by the April to October rainfall of 539 mm in 1985 (near normal) and 735 mm in 1986 (above normal). The total amount of irrigation was 243 mm in 1985 and 51 mm in 1986.

Gas sampling

The air to be analyzed was drawn through a Dekabon "1300" single-tube instrumentation line that consisted of a high density polyethylene jacket covering an aluminum layer covering a third inner ethylene copolymer coating (9.525 mm O.D. × 1.5748 mm wall thickness in 152-m lengths), inserted in an inverted polyethylene funnel mounted with the large opening above the soil surface in the plant row. The opening of the funnel was covered with fine nylon mesh to prevent insects and crop residue from entering the gas line. The gas sample lines extended from the center of the plots through adjacent plots along the soil surface back to a shelter, where the excess tubing was coiled, and then led into the instrument trailer. The material was weather and corrosion resistant with an aluminum layer which acted as an impermeable barrier to CO_2 concentrations near the soil surface.

The flow system shown in Fig. 1 was constructed to sample air at 12 locations. The locations represented eight air samples at 10 cm above the soil surface from one replicate of each experimental treatment, three samples taken at mid-canopy and a reference at 5 m adjacent to the plot area. The sample tubes at mid-canopy were elevated weekly as the canopy height increased. The gas sample lines (volume ~4.8 l) were sequentially purged using a large pump to draw the gas sample from the plot to the analyzer at 34 l min^{-1}. Thus, the gas lines were purged in ~10 s. A subsample of this air was withdrawn at 400 ml min^{-1} for analyses by an infrared gas analyzer (IRGA) (Analytical Development Company Model ADC-225-MK3) used in the absolute mode with the concentration range from 0 to 1000 μmol mol^{-1} to accommodate the high concentrations measured during the night.

The concentration of the standard gas used to calibrate the IRGA was nominally 400 μmol mol^{-1}. The IRGA was calibrated three times a week with calibrations that showed extreme drift as large as 10 μmol mol^{-1}, but in most cases the drift ranged from 2 to 4 μmol mol^{-1}. The extreme deviations were associated with power failures during electrical storms. For the most part, in-

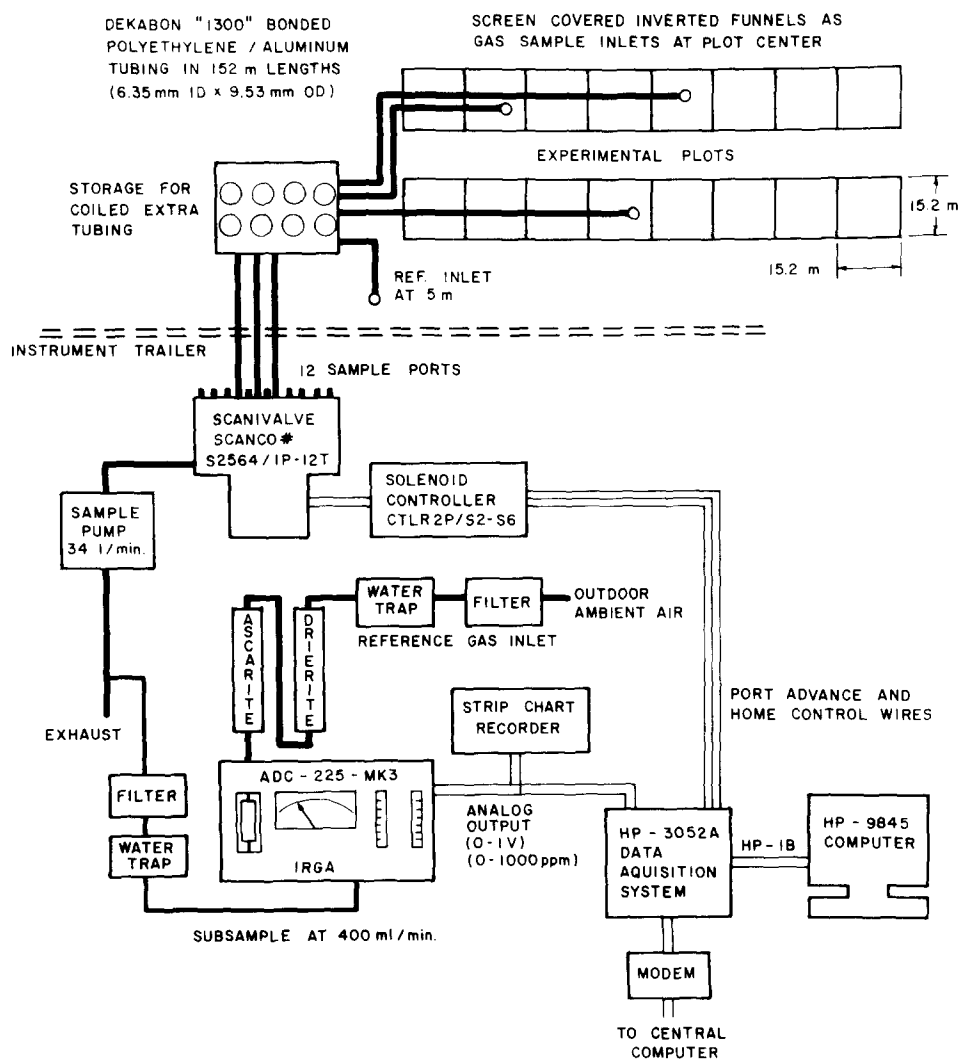## SCHEMATIC OF GAS SAMPLING EQUIPMENT

Fig. 1. Schematic representation of the gas sampling and measurement equipment.

strument drift between calibrations was small relative to the large fluctuations in CO_2 concentration.

Twelve gas sampling lines were connected to a Scanivalve (Code Number SAM-S6-12), a switching solenoid system that enabled multiple sampling lines to be sequentially run through one analyzer. The electrical pulses to switch the Scanivalve were provided by a computer-controlled data acquisition system. The timing and sampling sequence was similar for both years and is shown in

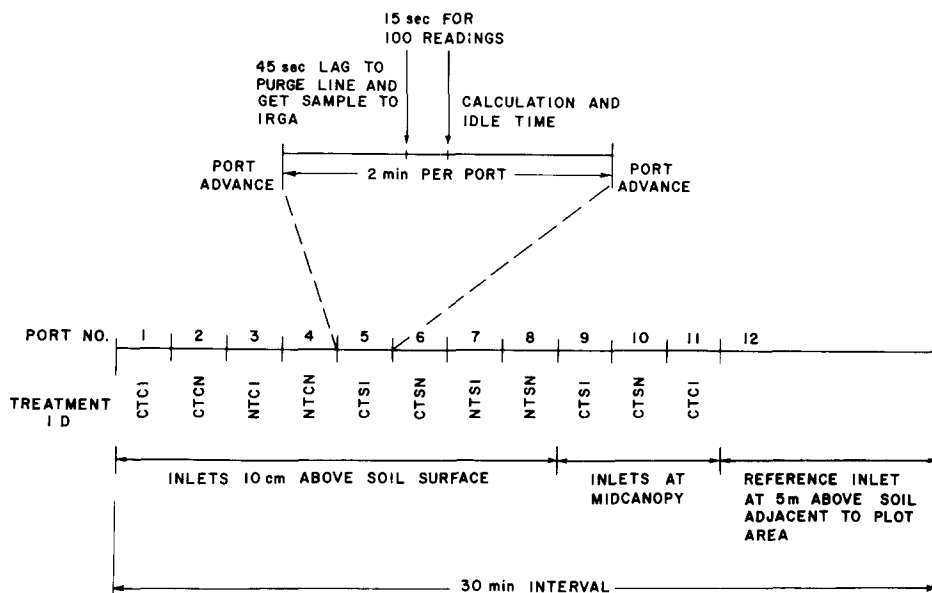1986   SCHEMATIC OF GAS SAMPLING SEQUENCE

Fig. 2. Schematic representation of the gas sampling sequence during the 1986 tillage–irrigation study.

Fig. 2 for 1986. The total time the switching solenoid valve was in one position was 2 min, 45 s as the measured lag time to get the air sample back to the IRGA and for purging the line and analyzer, and then a 15-s period of data collection where the analog signal from the IRGA was measured rapidly for a total of 100 readings. The remainder of the 2-min interval was for calculation of the mean and standard deviation. Thus 12 locations were scanned at 2-min intervals, resulting in a total sampling cycle of 24 min. The remaining time in the 30-min interval was spent on the reference sample located 5 m above the soil surface. This sequence was repeated every 30 min so that two readings per hour were obtained at each location. All of the gas sampling tubes had exactly the same length (152 m) so that only one lag time was required.

Microclimate data

Meteorological observations were made hourly at a weather station located adjacent to the experimental site. Observations included solar radiation measured with an Epply pyranometer, wind speed (minimum starting velocity of 0.4 m s^{-1}) and direction, aspirated and shielded air and dewpoint (lithium chloride dew cell) temperature. All observations were measured at 2 m. Air temperatures in the plant canopy near the gas sampling tubes were measured with shielded thermocouples at 15 cm above the soil surface and 0.6 m above

the canopy. The sensors above the canopy were moved upward as the canopy height increased. All the microclimate data were collected hourly using a calculator-controlled data acquisition system. Instantaneous values of solar radiation, wind speed and wind direction were obtained every 30 s and integrated to provide hourly readings. At the end of the 24-h period, the data were summarized, stored on magnetic media, printed on hard copy and transmitted to a larger central computer for further analysis. The data were collected from near planting to near harvest in both years.

In order to analyze the seasonal trends in the CO_2 concentration, the daily minimum and maximum values for a 24-h period were plotted as a function of time. Due to the extreme scatter in the minima and maxima, trend lines were drawn through the data points using a robust locally weighted regression (Cleveland, 1979). Robust locally weighted regression is a method for smoothing a scatterplot using a weighted least squares technique. The parameters selected to show the seasonal trends in the CO_2 concentrations were $f = 0.5$, n steps $= 2.0$ and $\Delta = 0$; where f represents the fraction of the points used in the smoothing operation, n is the number of iterations and Δ is a parameter to minimize computational time. Where the sole purpose of the smoothing operation is to enhance the perception of the trends in the plot, the choice of f is not critical. The same values of the input parameters were used in all graphs to enable comparisons to be made of seasonal trends during each of the 2 years of study.

RESULTS AND DISCUSSION

The LAI, biomass and plant height data for the conventional-tilled irrigated corn and soybean are shown in Fig. 3 for each of the 2 years. The no-till and non-irrigated treatments were essentially the same and are not shown. The corn was taller with a smaller LAI than the soybean that had partially lodged later in the season. Both crops reached their maximum height and LAI at about the same time. It is noteworthy that a maximum soybean LAI of ~ 7.0 occurred at a height of 1 m, whereas corn had a maximum LAI of ~ 4.1 at a height of 2.8 m. The higher leaf area density of the soybean resulted in a more closed canopy that probably caused slightly higher maximum CO_2 concentrations, as discussed below.

Diurnal variation in CO_2 concentration

The effect of irrigation in 1985 on the CO_2 concentrations on a clear day followed by an overcast day is shown in Fig. 4. On the clear day, the CO_2 concentration was as low as ~ 305 μmol mol^{-1} and was related to the solar radiation and photosynthetic demand. However, on the overcast day there was a gradual increase in CO_2 during the night and then only a slight decrease during
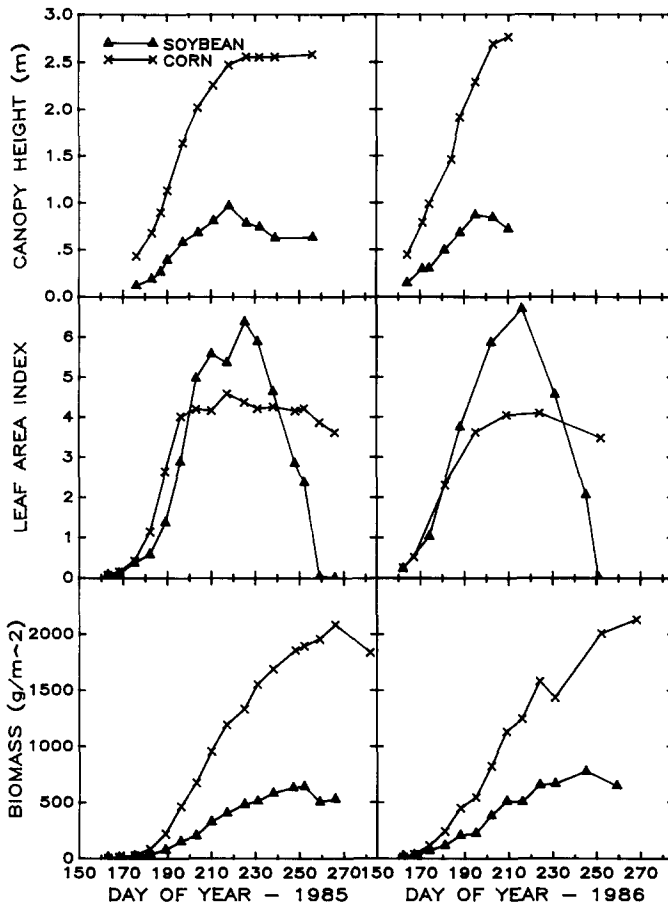
Fig. 3. Summary of *LAI*, plant height and biomass for the conventional-tilled irrigated corn and soybean for the 1985 and 1986 growing seasons.

the daytime hours. The small CO_2 fluctuations were associated with modest wind velocities (2–4 m s^{-1}) during the 2 days, and only during the night-time hours of DAY 194 with low wind was the increase in CO_2 > 550 μmol mol^{-1}. The effects of 54 mm irrigation on DAY 189 were minimal 4 days after the irrigation and 11 days after the last rainfall of 3 mm. Only on the overcast day with wind speed < 2 m s^{-1} was the CO_2 concentration on the irrigated plot slightly higher than that of the non-irrigated plot, apparently a result of the higher soil water content in the surface layer, as observed by Da Costa et al. (1986a, b) and Buyanovsky et al. (1986). The CO_2 concentration difference between irrigated and non-irrigated treatments, defined as Delta CO_2 in Fig. 4, shows oscillations around the reference line through DAY 193, then a tendency to increase between 10 and 30 μmol mol^{-1} on DAY 194. This difference needs to be interpreted with caution because of the sequential sampling em-
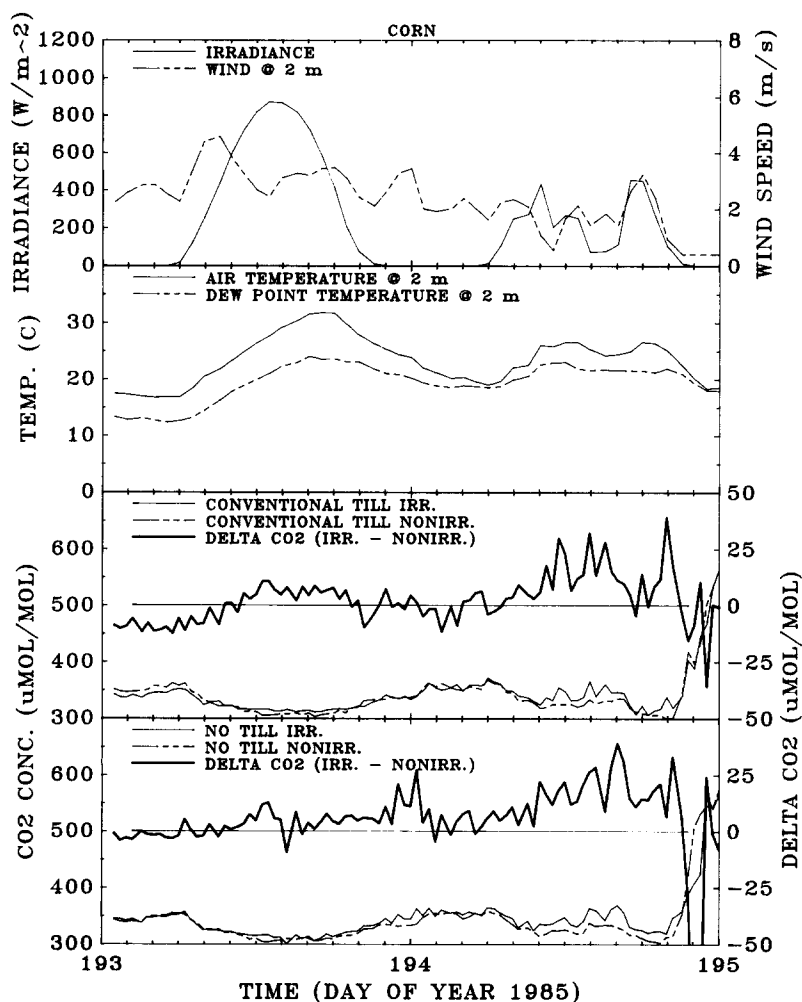
Fig. 4. Example of the CO_2 concentrations at 10 cm as affected by microclimate during the 1985 growing season, comparing irrigated and non-irrigated corn. Delta CO_2, defined as the CO_2 concentration difference between irrigated and non-irrigated corn, is plotted with the zero line for reference.

ployed and fluctuating wind velocities. When the CO_2 concentration changes rapidly, large differences can appear that may not be accurate due to the time difference between measurements. Nevertheless, there is a tendency for both the conventional-till and no-till irrigated plots to have a higher CO_2 concentration. The effect of solar radiation on the diurnal fluctuation was minimal and the magnitude of the CO_2 concentration was primarily controlled by wind velocity (Verma and Rosenberg, 1976). No other differences due to irrigation were observed in 1986 due to the high rainfall.
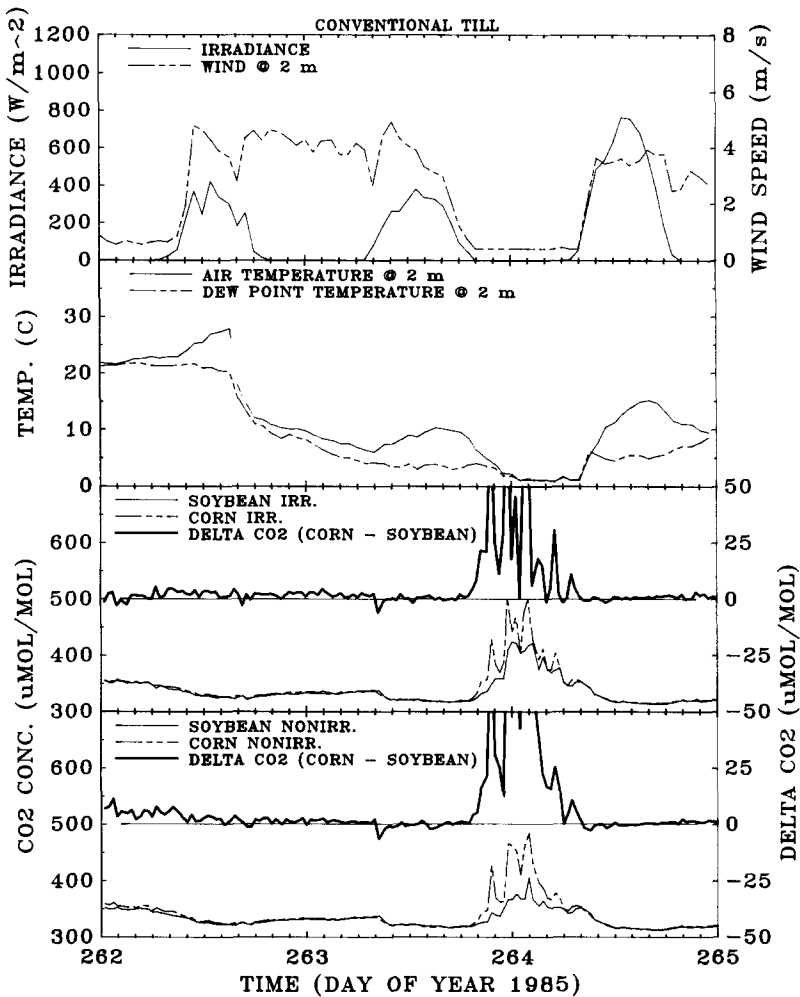
294

Fig. 5. Example of CO_2 concentrations at 10 cm as affected by a dramatic change in air temperature during the 1985 growing season. Delta CO_2, defined as the CO_2 concentration difference between corn and soybean treatments, is plotted with the zero line for reference. The soybean leaves had already completely senesced at this time, and the first frost occurred on DAY 264 as a result of the low wind and low temperatures.

Figure 5 illustrates the limited effect of a dramatic change in air temperature under high wind speeds on the CO_2 concentrations late in the 1985 season. Air temperature showed a decrease of 16°C within 2 h as a cold front passed. The further gradual decrease in temperature until DAY 264, when there was a light frost, showed only a minor effect on CO_2 concentrations. The relatively constant CO_2 concentrations were a result of high wind velocity and turbulent mixing. Only when the winds dropped below 0.5 m s^{-1} did the CO_2 concentra-

tion increase in the canopy. There was little difference between irrigated and non-irrigated plots, and only a slightly higher concentration in the corn during the night of DAY 263. In this case, Delta CO_2, defined as the difference between corn and soybean in the lower sections of Fig. 5, was as large as 50 μmol mol^{-1} during the low wind period on DAY 264. The slightly higher CO_2 concentration was apparently due to corn plant respiration. Most corn plants were still green at DAY 263 while the soybeans were mature with 100% leaf drop.

Large and repeated diurnal fluctuations in CO_2 concentrations during mid-season in 1986 are illustrated in Fig. 6. There were three consecutive days when the maximum CO_2 concentration during the night ranged from 550 to 700 μmol
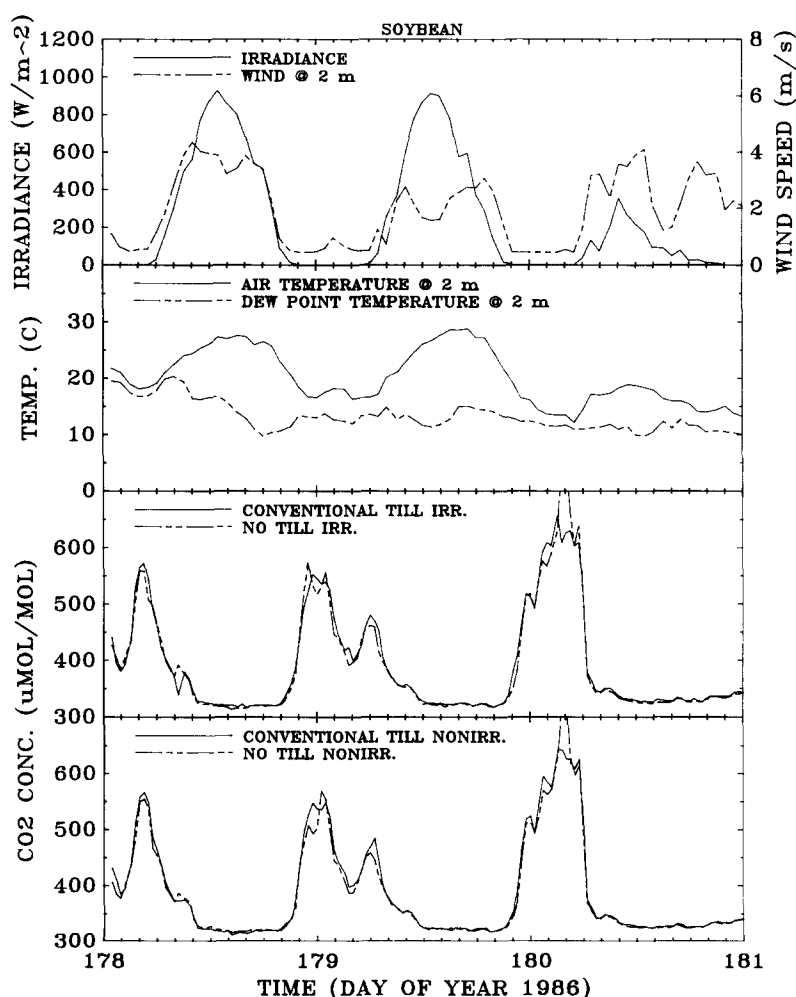
Fig. 6. Example of the CO_2 concentration at 10 cm during 3 days in the 1986 growing season, illustrating consecutive large diurnal fluctuations.

mol^{-1} and the minima during the daylight hours ranged from 305 to 310 μmol mol^{-1}. These large diurnal fluctuations were inversely related to the wind speed, which agrees with the observations of Allen (1971), Brown and Rosenberg (1970, 1971), and Verma and Rosenberg (1976). There was little effect of solar radiation on the daily minima because the first 2 days were relatively clear and the last day was overcast. The tillage and irrigation treatments had no effect on CO_2 minima. Similar trends were also observed in 1985 (data not shown).

Seasonal trends in CO_2 concentration

In order to analyze seasonal trends in CO_2 concentration, the daily minimum and maximum CO_2 values were plotted against time. An example for conventional-till corn at the 10-cm height is shown in Fig. 7 for 1986. Immediately evident are the large fluctuations in the daily maximum values that generally occur during the night and the relatively small fluctuations in the daily minima that normally occur during the day. In view of the large scatter in the individual data points on a daily basis, trend lines were drawn through the data points using the robust locally weighted regression (Cleveland, 1979). This is illustrated in Fig. 7 where the daily minimum and maximum concentrations were separated to amplify the range of the minimum CO_2 concentrations (note the change in scale). The seasonal CO_2 maximum occurred during flowering near DAY 215 in 1986, $\sim$80 days after planting. This was probably the time of greatest plant and soil respiration, although the methods used in this study do not permit differentiation between these sources. The minimum concentration does show a seasonal trend that decreases from $\sim$330 to $\sim$305 μmol mol^{-1} that also occurred near anthesis. Later in the season, the minimum CO_2 concentration increased as the plants senesced. While there is considerable scatter in the individual daily minimum and maximum values throughout the growing season, the trend lines indicate CO_2 depletion within the plant canopy during the daylight hours. Similar results have been reported for corn (Chapman et al., 1954; Allen, 1971), soybeans (Da Costa et al., 1986) and sugar beets (Brown and Rosenberg, 1970).

The scatter in the individual minimum and maximum for the other treatments, both at 10 cm and at mid-canopy, was similar to that in Fig. 7. Comparisons through the season based on position within the canopy and treatment effects will be illustrated using only the trend lines. Based on the magnitude of the variation shown in Fig. 7, the difference between the trend lines needs to be interpreted with caution.

The seasonal trends in the daily minimum and maximum within the soybean crop in 1986 are shown in Fig. 8. The seasonal minimum occurred on about DAY 215 (3 August) when there was maximum canopy development (see Fig. 3). The minimum values showed essentially the same trend with no difference
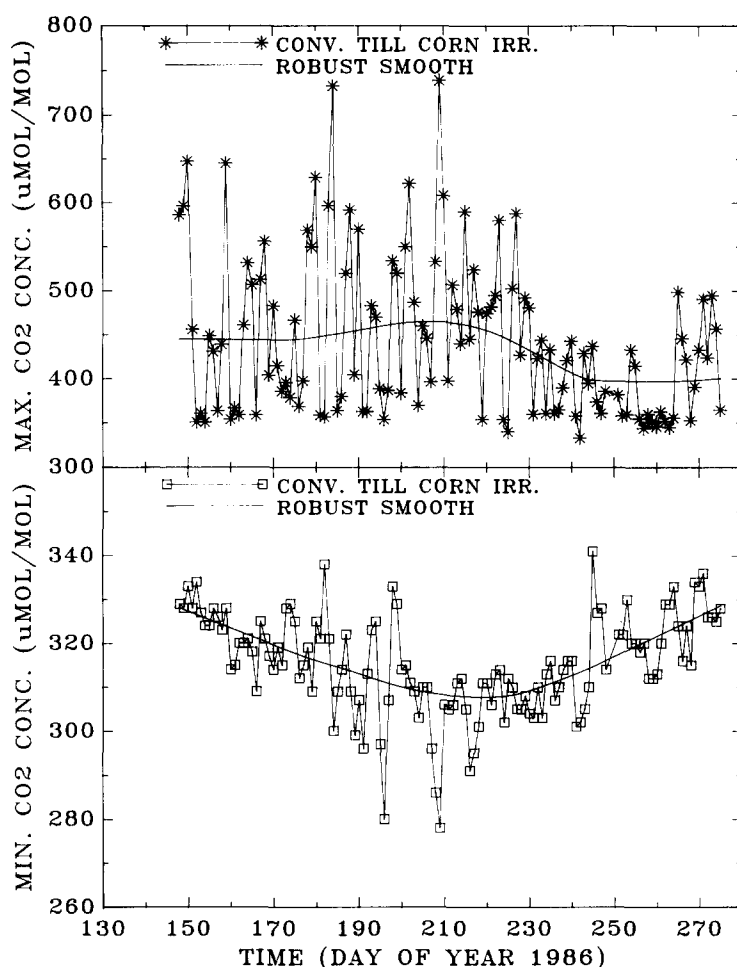
Fig. 7. The seasonal trends in the daily minimum and maximum values of CO_2 at the 10-cm height for conventional-tilled irrigated corn during the 1986 growing season. These graphs show the individual data points and the smooth trend line from the robust locally weighted regression. Note the scale change on the y axis.

between the minimum CO_2 concentration at 10 cm and at 5 m. However, there is a larger difference in the maximum CO_2 concentrations in the soybean canopy and at the 5-m level. Consistently throughout the season, the maximum CO_2 concentrations at 10 cm in the soybean canopy were larger than at 5 m and much larger compared to the corn at 10 cm. These results suggest that the air was more stable within the denser soybean canopy (Allen et al., 1974; Desjardins et al., 1978). The seasonal trends in the daily minima and maxima were essentially the same; however, the magnitude of the maximum in corn was consistently less than that in soybean.
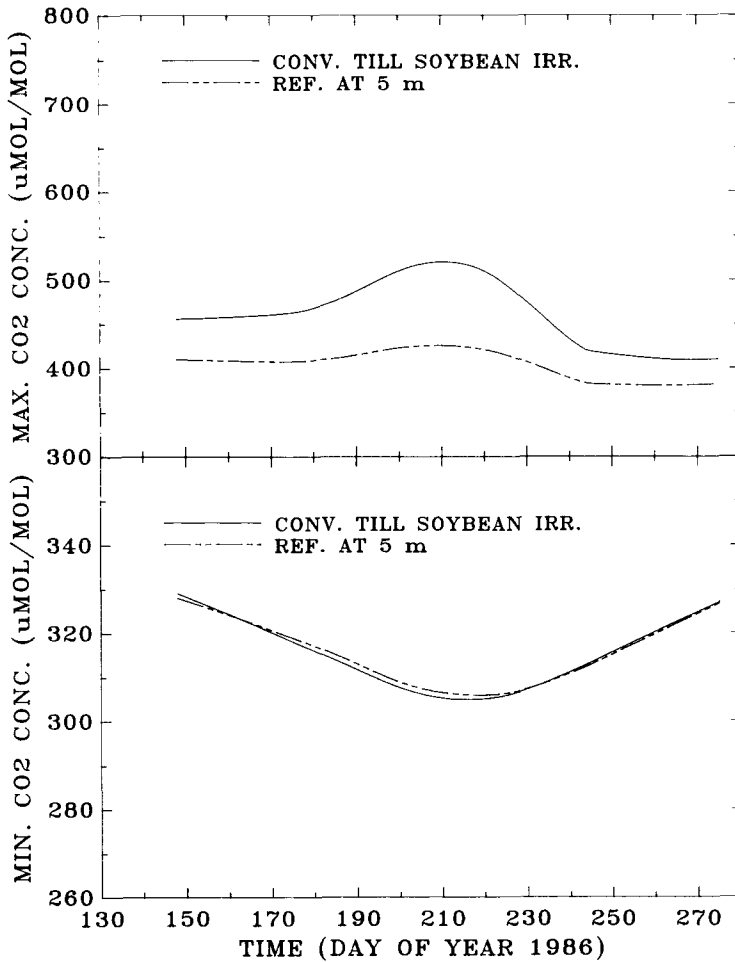
Fig. 8. The seasonal trends for conventional-tilled irrigated soybean, comparing the daily minimum and maximum values at 10 cm with the reference at 5 m. Note the scale change on the y axis.

A sample of the seasonal trends for the daily maximum and minimum concentration at the 10-cm level and mid-canopy for the conventional-till corn is illustrated in Fig. 9. There was no apparent difference in the maximum concentration trend lines throughout the entire growing season. However, the minimum CO_2 concentration throughout the season at mid-canopy was considerably less than that measured at 10 cm. This reflects plant demand for CO_2 at mid-canopy (Chapman et al., 1954; Allen, 1971; Harper et al., 1973a, b) and probably the higher CO_2 concentrations at 10 cm as a result of soil respiration (Monteith et al., 1964; Buyanovsky et al., 1986).

The daily minimum and maximum trend lines showed essentially the same relationship for both tillage methods (data not shown), even though the no-
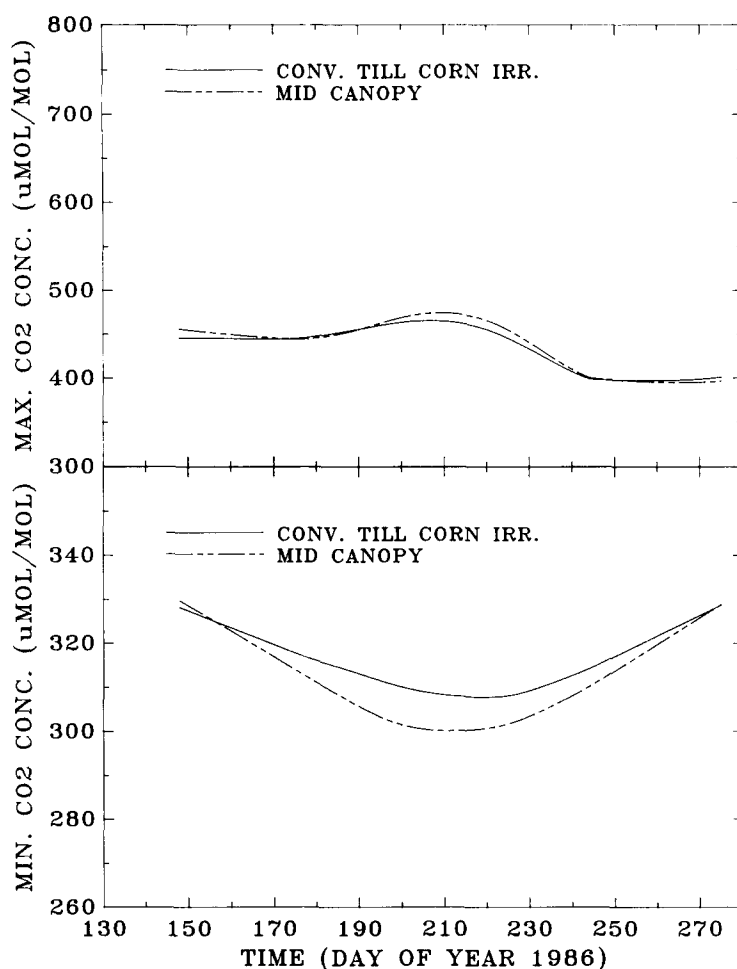
Fig. 9. Seasonal trends in the CO_2 concentrations in conventional-tilled irrigated corn, comparing the daily minimum and maximum CO_2 concentrations at 10 cm and at mid-canopy. Note the scale change on the y axis.

till system had substantial corn residue on the surface from the previous years. While it is not possible to separate the soil respiration contribution to the CO_2 concentration at this level, the lack of any difference between the two tillage methods suggests that residue decomposition on the surface of the no-till plots contributes little usable CO_2 to the canopy. Apparently, the turbulent mixing within the canopy over both tillage systems is sufficient to completely mix the CO_2 under the canopy and results in little difference in CO_2 available to the crops for photosynthesis.

The largest treatment differences in any of the seasonal trends were between the corn and soybean on the conventional-till plots (illustrated in Fig. 10).
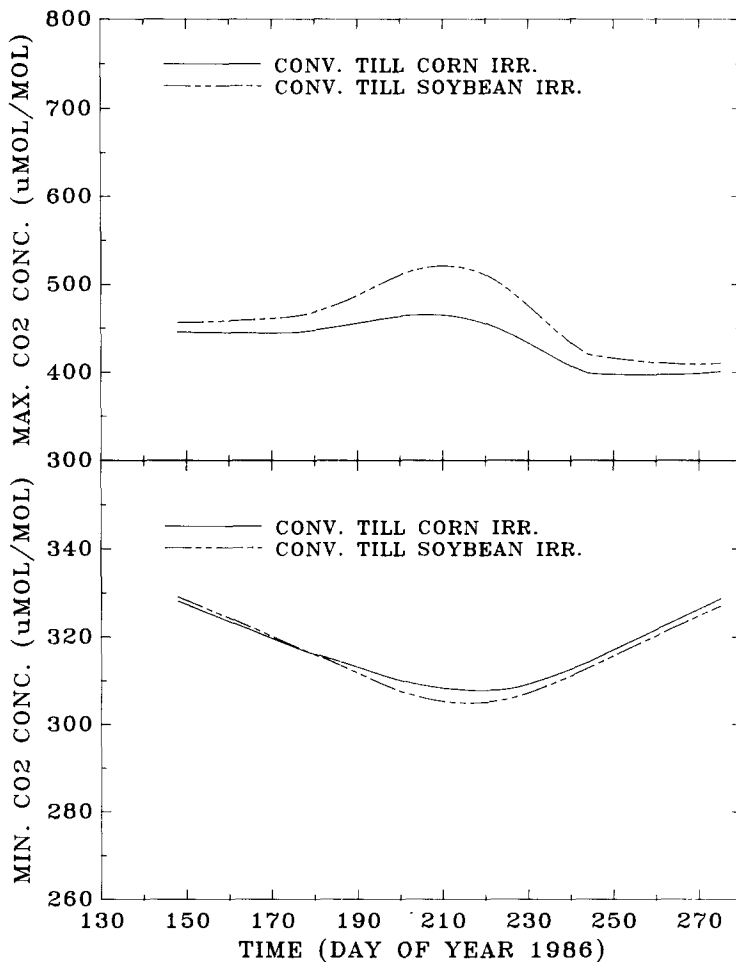
Fig. 10. Seasonal trends in the CO_2 concentration at 10 cm in conventional-tilled irrigated corn and soybean. Note the scale change on the y axis.

The minimum trend line for the soybean was only slightly lower than that for the corn during the middle of the growing season. However, the maximum trend lines show that the maximum CO_2 concentration in the soybean canopy was consistently higher than that in the corn throughout the entire season. Da Costa et al. (1986a, b) found that respiration of a soybean crop was primarily attributable to the aerial parts (87–93%) and the remainder to soil and root respiration. While some of this difference in the maximum CO_2 concentration may be related to plant respiration and species difference (Rosenberg, 1981; Kramer, 1981), it is impossible to separate the effect of canopy structure on the CO_2 concentration in the canopy at 10 cm. In this case, the LAI for corn was as high as 4.1, but was distributed over a canopy height of 2.8 m. Soybean

had a denser canopy, with *LAI*s between 6 and 7 that were distributed over a canopy height of ~ 1.0 m. Part of the difference between the corn and soybean was probably related to canopy *LAI* and structure, as is predicted by the model of Takami and van Bavel (1975). Their results showed that the efficiency of CO_2 enrichment for a canopy with *LAI* of 8 was 24% higher than that for a canopy with *LAI* of 3.5.

Seasonal trends similar to those shown in Figs. 8, 9 and 10 were observed on other treatments in both years, but treatment differences were not substantial. Analysis of the smooth trend lines on a seasonal basis showed that the effects of irrigation and tillage were minor throughout both seasons. Occasional large diurnal fluctuations with maximum CO_2 concentrations at night were associated with low winds and high temperatures and maximum plant growth. Smaller fluctuations with windy conditions were related to diurnal changes from photosynthesis and respiration.

The diurnal patterns of CO_2 concentration in the crop canopy showed a strong dependence on solar radiation and wind speed. Typical diurnal variations were larger than others in the literature due to the close proximity of the soil surface. With high light intensity, the midday CO_2 concentration decreased to as low as 285 μmol mol^{-1} and then showed a gradual increase after sunset. On days with lower radiation, the CO_2 concentration was not as low as a result of the combined effect of reduced photosynthesis and soil and plant respiration. The largest fluctuations in the CO_2 concentration during the summer months were noted when the vegetative mass was greatest under low winds.

In summary, the CO_2 concentrations measured in the plant canopy were very dynamic and strongly related to the microclimate, primarily the wind velocity and plant exchange through respiration and photosynthesis. Extreme minimum and maximum CO_2 concentrations ranged from 285 to 800 μmol mol^{-1} on a daily basis for the 2 years of the study. However, typical minimum and maximum values ranged from 320 to 450 μmol mol^{-1}. Seasonal trends in the CO_2 concentration showed that both maximum and minimum CO_2 concentrations occurred around flowering which corresponded to maximum canopy development for both corn and soybean. The soybean had a 50–60 mol mol^{-1} higher maximum CO_2 concentration than the corn (Fig. 10), apparently related to the higher leaf area density, that resulted in a more closed canopy. However, possible differences between the C3 and C4 species discussed by Rosenberg (1981), Kramer (1981) and Da Costa et al. (1986a, b) cannot be overlooked. The effects of irrigation and tillage were generally not significant, suggesting adequate ventilation within both canopies that resulted in CO_2 concentrations at 10 cm that were not affected by the soil management practice. The microclimate, primarily wind velocity > 0.5 m s^{-1}, appears to be the major controlling factor of the CO_2 concentration in the plant canopies (Brown and Rosenberg, 1970, 1971; Knipling et al., 1970; Allen, 1971; Allen et al., 1971; Verma and Rosenberg, 1976; Desjardins et al., 1978). These results obtained

under field conditions are in agreement with model predictions (Waggoner, 1969; Allen et al., 1971; Takami and van Bavel, 1975). CO_2 from soil respiration modified by soil and water management practices would not be efficiently used as a fertilizer due to turbulent mixing and rapid loss of CO_2 through the canopy to the atmosphere.

ACKNOWLEDGMENTS

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